Geographic variation and genetic performance of *Picea koraiensis* in growth and wood characteristics

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Abstract: Eight provenances of 19-year-old *Picea koraiensis* Nakai from the provenance trials of Maoershan (45°20'N, 127°30'E), Liangshui (47°10'N, 128°53'E) and Jiagedaqi (50°24'N, 124°07'E) in Northeast China were investigated to analyze the genetic variation in growth characteristics (tree height and diameter) and wood characteristics (tracheid length, tracheid diameter, tracheid wall thickness, annual ring width as well as wood density). Great variation in height growth and breast height diameter growth was observed among the provenances, and along with the increase of tree age, these provenances presented different geographic adaptability. The growth characteristics of *Picea koraiensis* stand at age of 10 in Maoershan and Liangshui provenance trials had a positive correlation with longitude, and with increase of tree age to 15 and 19, the tree growth of the provenances displayed a significant positive correlation with latitude as well as altitude. For wood characteristics, great variation was also found among the provenances. There exists a close relation between growth characteristics and wood properties of the provenance. The height and breast height diameter growth of the provenance had a positive correlation with tracheid diameter and annual ring width, and a negative correlation with tracheid wall thickness and wood density. Genetic performance of the provenance in all above characteristics was also investigated in order to provide more useful information for comprehensive selection of this species for pulpwood and plywood production.

Keywords: *Picea koraiensis*; Geographic variation; Genetic correlation; Growth characteristics; Wood characteristics

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Introduction

Picea koraiensis Nakai is an important reforestation species in northeast part of China, which has many advantages such as fast growth, high adaptability, fine structure, white color, as well as strong strength of the wood, thus it has great potential as pulpwood, board and plywood.

Tree improvement of *Picea koraiensis* in provenance level was carried out in China from the beginning of the 1980s. The trials were established in 1984. Some primary results had been achieved in this area, including geographic variation of the provenance, early selection, cutting propagation, etc. (Yang 1993; Wang 1993, 1997). In this study, the provenance materials of 19 years old *Picea koraiensis* from three trials were used to study geographic variation and genetic performance in both of growth and wood characteristics. Besides, the relationships among these characteristics were also analyzed in order to provide basic information in provenance selection for timber directional production.

Materials and methods

Materials

Samples separately came from three provenance trials of Maoershan (45°20'N, 127°30'E) and Liangshui (47°10'N, 128°53'E) Forestry Farms of Northeast Forestry University, as well as Jiagedaqi (50°24'N, 124°07'E) in Daxing'anling Forest Bureau. Eight provenances for each trial were involved (see Table 1), which were planted in double rows per plot with 100 trees, five replications and spacing in 1.5 m × 2.0 m.

Methods

The growth characteristics (tree height and diameter at breast height) and wood characteristics (annual ring width, relative wood density, tracheid length, tracheid diameter or width, thickness of the tracheid wall, and ratio of tracheid length and diameter) were measured.

Height and diameter growth for all the trees of the provenances were separately measured every year in the early stage and every 4-5 years after 10-year growth.

The wood samples of 19 years old *Picea koraiensis* were collected from Maoershan and Liangshui field trials 5 trees per provenance. To avoid within tree variation, all samples were taken at the tree base with a height of 40 cm above the ground. After cutting in the field, the materials were placed in the plastic bag, brought to the laboratory and processed immediately. And then, the wood samples were treated and measured according to national standard test methods of wood physical and mechanical properties (GB1933-91 etc.).

Variance analysis was used to study the provenance variation for all above characteristics, and correlation among growth and wood properties were also calculated with STATGRAF software.

Table 1. Geographic factors of the provenances

Provenances	Longitude (E)	Latitude (N)	Altitude(m)
Tianqiaoling (TQL)	129°46'	43° 26'	242.7
Muling (ML)	130°20'	44° 30'	266.1
Caihe (CH)	129°45'	44° 35'	273.6
Huanan (HN)	130°31'	46° 12'	182.4
Jishantun (JST)	127°15'	48° 47'	296.5
Wuyiling (WYL)	129°25'	48° 40'	300.0
Aihui (AH)	126°48'	49° 37'	160.0
Gangfeng (GF)	125°14'	49° 26'	242.2

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Results

Geographic variation in growth characteristics

Genetic variation of these provenances was reported twice before this study. A little different result was observed this time, but the differences in growth characteristics of *Picea koraiensis* measured at the ages 10, 15 and 19 were still significant among the provenances for all three trials (see Table 2).

Table 2. Variance analysis of the provenance growth characteristics of *Picea koraiensis* in different trials

Trials	Age (Year)	Characteristics	F value	Variation range
Maoershan	10	Height (m)	4.30**	0.85-1.17
	10	Diameter (cm)	3.45**	2.12-2.98
	15	Height (m)	4.02**	2.27-3.51
	15	Diameter (cm)	4.54**	2.97-4.63
	19	Height (m)	4.16**	3.62-4.31
	19	Diameter (cm)	3.30**	4.15-5.71
Liangshui	10	Height (m)	6.37**	0.75-1.17
	10	Diameter (cm)	3.97**	2.14-3.11
	15	Height (m)	7.14**	2.43-3.09
	15	Diameter (cm)	6.48**	2.83-4.20
	19	Height (m)	4.37**	3.35-4.72
	19	Diameter (cm)	4.78**	4.44-6.14
Jiagedaqi	10	Height (m)	10.44**	0.90-1.18
	10	Diameter (cm)	4.80**	2.12-2.50
	15	Height (m)	7.28**	1.21-2.10
	15	Diameter (cm)	3.06**	1.01-1.76

Note: ** means significant level in 0.01.

The correlation between growth characteristics and geographic factors where the provenance was located at showed that the geographic variation pattern in growth characteristics changed along with the increase of the tree age. For the provenance at age of 10, the height and diameter growths had a positive correlation with longitude in Maoershan and Liangshui trials, with a correlation coefficient of around 0.6, and in Jiagedaqi trial, these two growth characteristics had a strong positive correlation with latitude (0.66–0.76) and a weak negative correlation with longitude (-0.48–0.49) (Table 3). As to the provenance at age of 15, the height and diameter growth started to display a significant positive correlation with altitude in both of Liangshui and Jiagedaqi trials, but not in Moershan trial. In Maoershan trial, height and diameter growths of the provenances showed a decease trend along with latitude, with a coefficient of 0.6–0.7. For the provenance at age of 19, the growth characteristics had more significant correlation with altitude in both of Maoershan and Liangshui trials, whose coefficient was around 0.65–0.83.

Geographic variation in wood characteristics

In this study, we also found great variation in wood characteristics of *Picea koraiensis* among provenances, such as tracheid length, tracheid diameter, tracheid wall thickness, annual ring width, and relative wood density (see Table 4). The correlation analysis from the data in Liangshui trial demonstrated that there existed some correlations between wood characteristics and geographic factors. For example, a negative correlation was found between longitude and ratio of tracheid length and diameter, as well as between longitude and thickness of the tracheid wall, with the correlation coefficients above -0.4, and a little strong positive correlation was also found between latitude and tracheid length and ratio of tracheid length and diameter, with a coefficient around 0.55, and between altitude and tracheid length and diameter with coefficients about 0.5, but all of them are not in a significant level (Table 5). The same result was achieved in Maoershan trial.

Table 3. The correlation between growth characteristics of geographic factors of *Picea koraiensis* in three different trials

Trials	Age	Characteristics	Longitude	Latitude	Altitude
Maoershan	10	Height (m)	0.629*	-0.218	0.208
	10	Diameter (cm)	0.610*	-0.177	0.252
	15	Height (m)	-0.334	-0.521	0.242
	15	Diameter (cm)	-0.432	-0.586*	0.198
	19	Height (m)	0.363	-0.320	0.834*
	19	Diameter (cm)	0.331	-0.429	0.659*
Liangshui	10	Height (m)	0.666*	0.389	- 0.510
	10	Diameter (cm)	0.591*	0.257	- 0.453
	15	Height (m)	0.118	-0.353	0.698*
	15	Diameter (cm)	0.072	-0.379	0.654*
	19	Height (m)	0.381	-0.431	0.773*
	19	Diameter (cm)	0.476	-0.409	0.774*
Jiagedaqi	10	Height (m)	-0.484	0.767*	0.325
	10	Diameter (cm)	-0.492	0.656*	0.171
	15	Height (m)	0.063	-0.224	0.662*
	15	Diameter (cm)	0.265	-0.388	0.686*

Note: * means significant level in 0.05

Table 4. Variance analysis of growth and wood characteristics of *Picea koraiensis* for different provenances

Trials	Characteristics	F Value	Variation range
Maoershar	Annual ring width (mm)	2.28*	2.78-3.39
	Relative wood density ($g \cdot cm^{-1}$)	9.04**	0.44-0.49
	Ratio of tracheid length and diameter	6.75**	67.4-80.8
	Thickness of tracheid wall (μm)	4.57**	0.14-0.20
	Tracheid length (mm)	1.53	1.81-2.07
	Tracheid diameter (μm)	1.98	25.6-27.3
Liangshui	Annual ring width (mm)	13.72**	2.42-3.89
	Relative wood density ($g \cdot cm^{-1}$)	17.58**	0.38-0.46
	Ratio of tracheid length and diameter	4.05**	54.4-64.4
	Thickness of tracheid wall (μm)	10.22**	0.13-0.21
	Tracheid length (mm)	9.13**	1.37-1.72
	Tracheid diameter (μm)	5.95**	25.5-29.4

Note: ** means significant level in 0.01, * means significant level in 0.05.

Table 5. Correlation analysis of wood characteristics of *Picea koraiensis* and geographic factors in Liangshui trial

Geographic factors	Wood characteristics: Trachied length	Tracheid diameter	Ratio of tracheid length and diameter	Thickness of tracheid wall
Longitude	-0.393	0.006	-0.498	-0.417
Latitude	0.533	0.104	0.569	0.158
Altitude	0.492	0.554	0.249	-0.010

Genetic performance in growth and wood characteristics among the provenances

The differences in height growth among the provenances in

Maoershan and/or in Liangshui trials were remarkable, and the variation trends were the same. That meant the best provenances in height growth, i.e. Jishantun, Wuyiling and Caihe provenances, in Maoershan trial also had better height growth in Liangshui trial (Fig. 1A). The situation was not quite same in wood characteristics between the two trails. Some provenances had the highest values in wood characteristics in both trials, such as wood density and tracheid wall thickness in Gangfeng provenance, wood density and tracheid length/tracheid diameter in Huanan provenance, but some had opposite result like tracheid wall thickness in Huanan provenance and wood density in Caihe provenance (Fig. 1B, C, D).

Generally to consider growth and wood characteristics, it could be seen that some provenances with high growth potential did surely had a good performance in wood characteristics, for instance, Wuyiling and Caihe provenances in height growth, wood density, and tracheid length/tracheid diameter. Still some provenances like Gangfeng provenance were better in wood quality but lower in height growth.

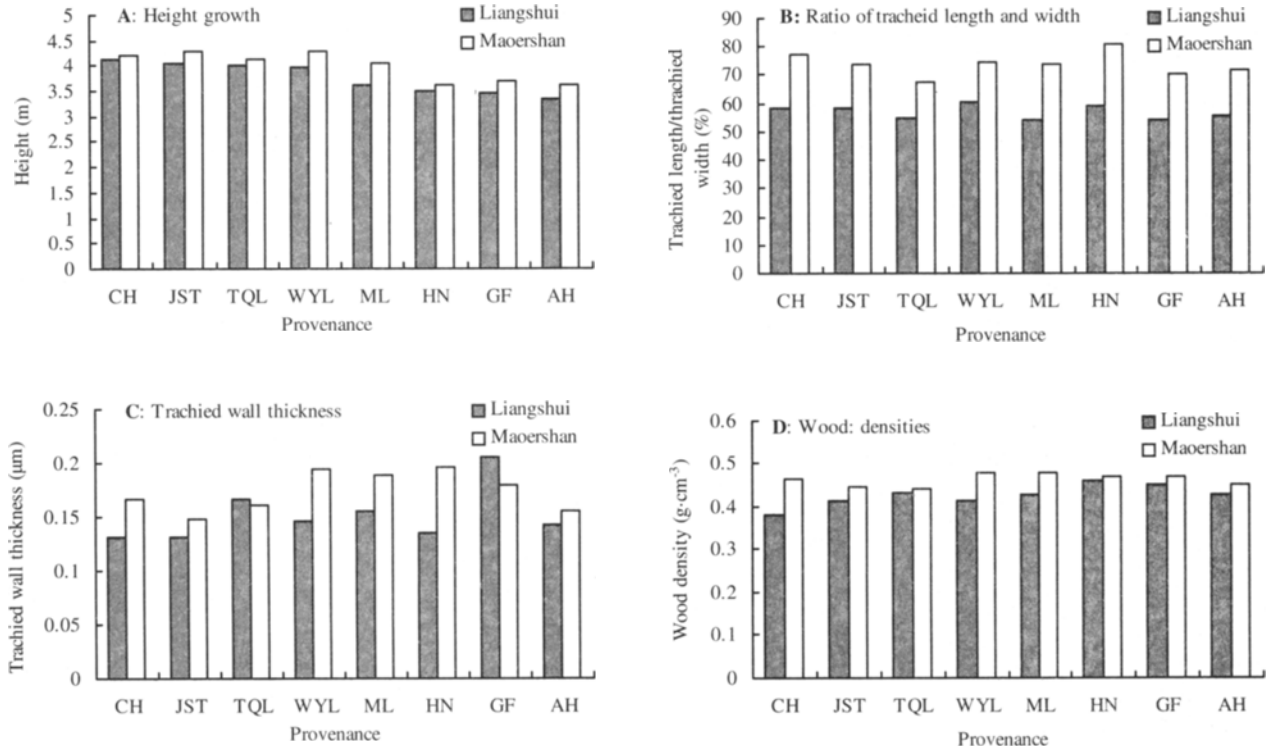

Fig. 1 Height growth (A), Ratio of tracheid length and width (B), Trachied wall thickness (C), and wood density (D) among different provenances in Liangshui and Maoershan trails

Note: CH: Caihe; JST: Jinshantun; TQL: Tianqiaoling; WYL: Wuyiling; ML: Muling; HN: Huanan; GF: Gangfeng; AH: Aihui provenances

Correlation between growth and wood characteristics

The tracheid length and annual ring width had a great positive correlation with growth characteristics, with a correlation coefficient over 0.6. There existed significant relations among tracheid length, tracheid diameter and annual ring width. Some strong positive correlations existed in tracheid length and diameter, with a coefficient of 0.635, and between annual ring width and tracheid length as well as diameter with the coefficient over 0.62. Besides, there existed some negative correlations between annual ring width and the thickness of tracheid wall, and between annual ring width and wood density, with coefficients around –0.57––0.59 (see Table 6). The wider the annual ring was, the longer and wider the tracheid, the lower the wood density was. This situation should be considered when the provenance is selected for pulpwood and plywood in the future.

Table 6. Correlation analysis among growth and wood properties of the provenances in Liangshui trial

Characteristics	Height	Breast height diameter	Tracheid length	Tracheid diameter	Thickness of tracheid wall	Relative wood density
Breast height diameter	0.925**					
Tracheid length	0.602*	0.672*				
Tracheid diameter	0.313	0.323	0.635*			
Thickness of the tracheid wall	–0.319	–0.445	–0.539	–0.027		
Relative wood density	–0.346	–0.392	–0.521	–0.194	0.223	
Annual ring width	0.685*	0.781*	0.623*	0.635*	–0.599 *	–0.573*

Note: ** means significant level in 0.01, * means significant level in 0.05.

Discussions

Provenance is the sources of seeds, seedlings, and other propagules, whose growth potential, wood quality, biotic and abiotic resistance, in general to say, have some well-regulated changes along with climatic and geographic factors where they are situated in their distribution area, thus forming geographic variation among the population within a species. In this study, the geographic variation has also been proven in both of growth and wood properties among the provenances, but the variation pattern is not quite clear because the trees are not mature enough. In Maoershan and Liangshui trials, growth characteristics of trees varied with longitude changes in early stage, and with the increase of the tree age, tree growth displayed a significant positive correlation with altitude and latitude evidently. In Jagedaqi trial, growth characteristics of the provenance at age of 10 had a significant correlation with latitude, and positively correlated with altitude at age of 15. That meant the provenances from high altitude grew better than those from low altitude. This result demonstrated that the provenance growth pattern could be gradually altered along with the increase of tree age and the changes of climate and soil condition of where the provenance originally came. Therefore, it is better not to make a premature conclusion when to study geographic variation rules of the provenance.

As is shown by many researchers, some wood characteristics are very important for the wood industry. Wood density and tracheid form have strong inheritance patterns, and the changes in these properties can have a significant effect on the final product. High wood density is usually favored, because it contributes to increase yield in pulp, and also to strength the properties of paper. Tracheid performance is probably the second important property because it has effects on the bulk, burst, tear, fold and tensile strength of the paper evidently. Also, thick tracheid wall tends to produce paper with poor printing surface and poor mullen strength (Zobel 1989, 1984). In our study, the wood density and tracheid characteristics of *Picea koraiensis* had significant variation among the provenances, but the change trend was not quite clear. Just some weak correlations were found between tracheid traits and geographic factors. The reason probably is that trees are still in juvenile stage, and the change in wood characteristics dose not fully exhibit.

In addition, a distinct interaction between genotype and environment in wood traits was observed in this study, for example, wood density in Caihe provenance was the highest among the provenances in Maoershan trail but it became the lowest one in Liangshui trial. The tracheid wall thickness in Huanan provenance also showed clear interaction in different experiment sites. It is quite necessary to know these kinds of interaction in wood production of this species, which concerns seed transfer among different areas and tree growth and timber production.

The combined selection according to growth and wood characteristics is an essential and useful way in Spruce wood improvement, all of which should depends on the variation and correlation among the characteristics. At present, there is no more favored result in this aspect. For this reason, the study should be continued for longer time in this species in order to obtain more reliable information for provenance selection in both of growth and wood quality.

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